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TRENDS AND VARIABILITY OF RAINFALL IN PUNJAB: A STATISTICAL ANALYSIS, 1981-2010

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Abstract

Rainfall patterns usually have spatial and temporal variability. Study of rainfall trend and variability not only reveals general trend of rainfall but also helps to identify changes in amount, intensity, frequency of extreme events and future projections at the regional scale. This variability affects key sectors of economy of a region particularly whose development is highly dependent on its water availability received from rainfall. This research paper provides an analysis of trends and variations in rainfall (1981-2010) for Punjab. The region was grouped into three climate zones, namely, arid zone, semi-arid zone and dry sub-humid zone. The analysis is based on a series of statistical tests designed to determine whether monthly and annual rainfall data is consistent, random and trend free. Mean rainfall, coefficient of variability and linear regression were analysed to get rainfall variability and trend.

Dry sub-humid recorded the highest precipitation followed by semi-arid and arid zone. However, rainfall trends within these zones are oscillatory. The temporal analysis reveals decreasing rainfall trend, among all zones. The overall analysis indicates random fluctuations in inter-annual variations and more variable rainfall which may lead to increased extreme events and increased vulnerability of the region.

Key words: *Rainfall Variability, Extreme Events, Punjab*

1. Introduction

Water is one of the most valuable natural resources that makes up 70% of the earth and is a sine-qua-non-to all forms of life (United Nations World Water Development, 2006). It is an important component in everyday life, from domestic use to national and global development. Water forms an integral part of development of human societies and amount or availability of water in any region to a large extent depends upon the amount of precipitation received in that region. Deficiency or excess of rainfall cause hydro-meteorological extremes such as floods and droughts. Variability of rainfall from season-to-season greatly affects the availability of soil moisture to plants. Hence, precipitation information is important for understanding crop productivity and hydrologic balance (Adler, Huffman, Bolvin, Curtis, & Nelkin, 2000).
Arid and semi-arid regions of the world are characterized by rainfall which is highly variable in space, time and quantity that result in water scarcity and low per capita water allocation (Farshad & Zinck, 1995). The situation is further worsened due to increase in population and associated urbanisation that imposes pressure on limited water resources. Understanding rainfall variability thus becomes important to manage scarce water resources that are under continuous threat of an increasing population, urbanization and economic

development. In regions like Punjab, that has heavy agriculture and industrial activities, water availability and scarcity is a serious issue (Vashisht, 2008). Moreover, economy is largely dependent on rains particularly on highly variable southwest monsoons.

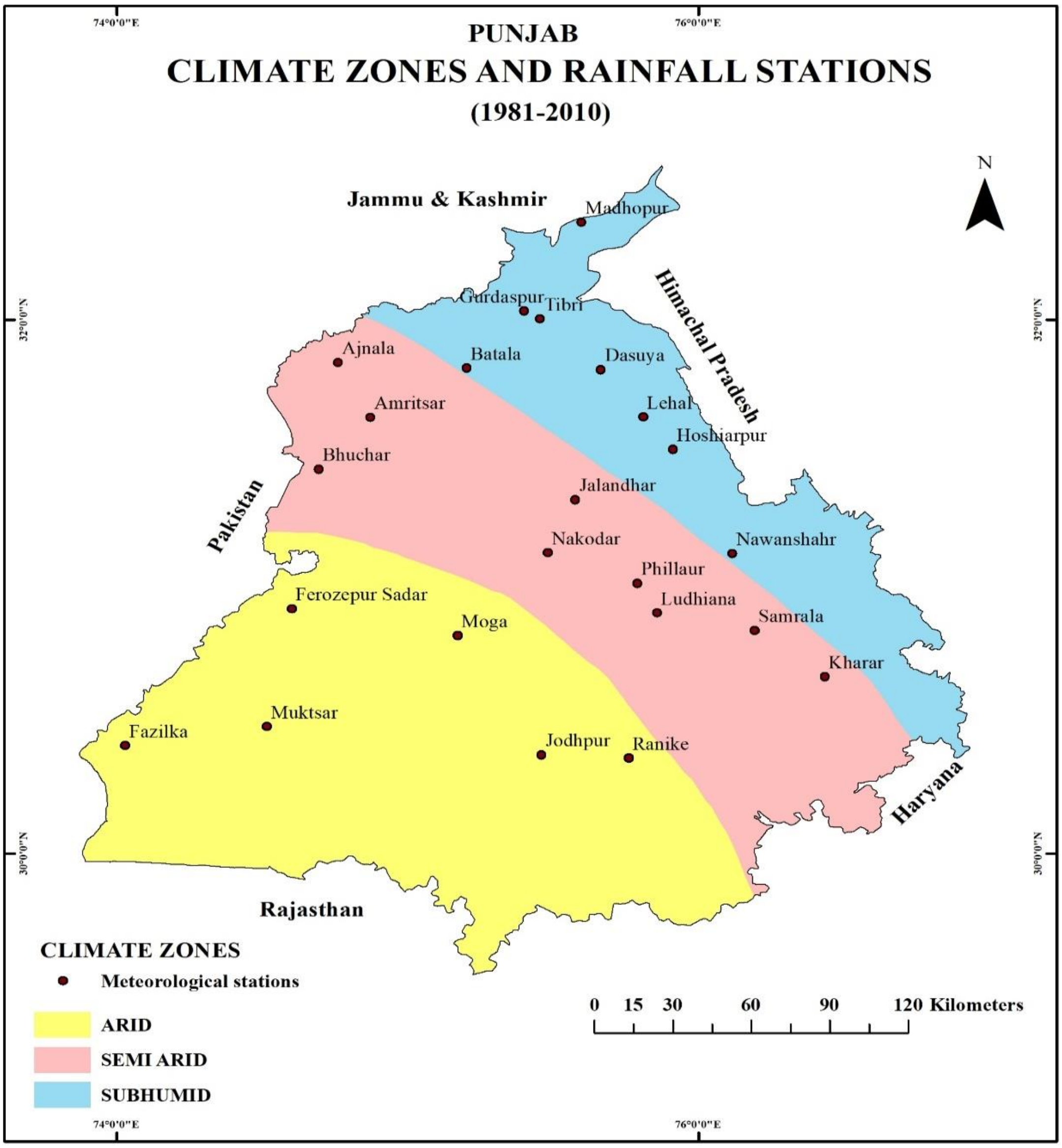
This situation demands an assessment of magnitude and variability of rainfall to provide information to better manage the agricultural activities such that impact of climate change as well as changes in land use can be assessed. This study outlines the spatio-temporal variation in annual and monthly rainfall for the period 1981-2010 in Punjab. Annual and monthly rainfall analysis can be used in the determination of crop water requirements, development of sectoral water allocation policies and management strategies under possible drought conditions.

2. Objectives of Study

The present study is aimed at the following objectives:

- To analyse the variability of monthly and annual rainfall among climatic zones of Punjab.
- To analyse the trends of monthly and annual rainfall among three climatic zones of Punjab.

Figure 1



3. Study Area

The present study is focussed on state of Punjab of northwest India. The study area is roughly a triangular region situated between 29°30′N to 32°32 ′N latitudes to 73°55 ′E to 76°50 ′E longitudes (Figure 1). The study area shares international border with Pakistan in the west and Himachal Pradesh in the northeast while Jammu and Kashmir lies in the north and Haryana, Rajasthan in south. Physiographically, this region is divided into 3 climatic zones that follow a sequence from South West (SW) to North East (NE) as: Arid Zone, Semi-arid zone and Dry Sub-Humid Zone. The elevation ranges from 180 metres in the southwest to 500 metres in the northeast.

Punjab's geography is climatically pivotal; the Himalayas in the north and east bar the infiltration of frigid katabatic winds from the Tibetan plateau and Central Asia. The Punjab Plains and Thar Desert (Rajasthan) in the south west plays a significant role in determining summer and winter temperature regimes. In addition, it also attracts moisture-laden southwest summer monsoon winds that provide over 60% of this region's rainfall.

The climate of the Punjab due to its geographical position is subject to great climate variability and extremes. This region has areas like Madhopur (Punjab) that receive very heavy rainfall while south-western Punjab plains receive scanty rainfall. Similarly, the range of temperature in this region is well over 46° Celsius making this region climatically diverse. Punjab is drained by Sutlej, Beas and Ravi basin. As Punjab employs heavy agriculture and industrial activities, water availability and scarcity is a serious issue. Moreover, economy is largely dependent on rains particularly on highly variable southwest monsoons. Since development of this region is highly dependent on water availability, any climatic fluctuations will enhance the vulnerability of this region.

This situation demands an assessment of magnitude and variability of rainfall to provide information to better manage the agricultural activities such that impact of climate change as well as changes in land use can be assessed. This study outlines the spatio-temporal variation in annual and monthly rainfall for the period 1981-2010 in Punjab.

4. Database and Methodology

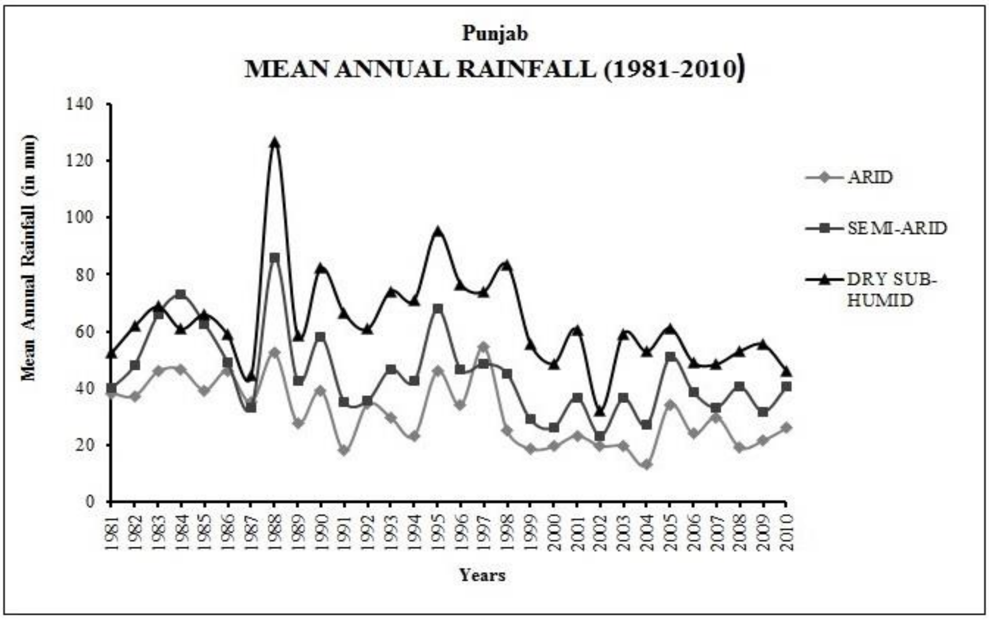
The methodology follows the statistical approach. Monthly precipitation data on Punjab was obtained from National Data Centre (NDC), India Meteorological Department (IMD), Pune and Directorate of Land Records, Jalandhar. The total monthly rainfall data of 28 meteorological stations for the period of 1981 to 2010 (Figure 1) representing three climatic zones, namely, arid, semi-arid, and dry sub-humid zones was considered for analysis. Statistical analyses were performed to assess any significant differences between three climatic zones and to illustrate the trend within the months and years under study. Measures of central tendency (mean, range), dispersion (standard deviation, coefficient of variability, variance), and distribution (skewness, kurtosis) were used to assess variability of rainfall. For identifying the trend in rainfall data, linear regression was used. The significance of trend line is shown by probability value (P value) for the significance level $\alpha = 0.05$. The value of R-square (R^2) or square of the correlation from the regression analysis was used to show relationship between variables years (X) and rainfall (Y).

5. Results and Discussion

5.1 Annual Rainfall Variability

The annual rainfall among three climatic zones (arid, semi-arid and dry sub-humid) in Punjab could be best described as oscillatory. From Figure 2 it is evident that the trend is not regular but irregular. However, comparing the three zones, it can be observed that that the semi-arid zone is more regular than the rest. The dry sub-humid zone has the highest oscillatory trend of rainfall. The higher precipitation recorded in the dry sub-humid zone could be attributed to the mountainous nature of the area, coupled with thick forests which supply sufficient amount of atmospheric moisture for precipitation.

Figure 2



Source: IMD, Pune and Directorate of Land Records, Jalandhar

The low rainfall in arid zone could be attributed to lesser vegetation in the area. In comparison to forests and mountainous area, loss of vegetation in arid zone reduces natural cooling by evapotranspiration. However, since precipitation in the tropical region is extremely variable in both space and time, identifying the precise cause of fluctuations remains challenging.

The rainfall range signifies the difference between maximum and minimum rainfall. The standard deviation and range indicate the variability of annual rainfall and hence denotes the reliability and persistence as constant source. To test whether annual rainfall data follows a normal distribution, the skewness and kurtosis were computed. Negative value of skewness indicate that data are skewed to left while positive values indicate data are skewed to right. Positive kurtosis indicates a peaked distribution while negative values indicate a flat distribution.

Table 1: Arid Zone: Descriptive statistics of annual rainfall (1981-2010)

Year	Mean (mm)	Median (mm)	S. D (mm)	Variance (mm)	Skewness	Kurtosis	Min (mm)	Max (mm)	Range (mm)
1981	38.27	19.32	67.92	4613.33	3.23	10.81	2.13	249.72	247.59
1982	37.27	24.96	39.99	1599.43	2.32	6.16	1.88	150.01	148.13
1983	45.89	27.40	47.25	2232.17	1.24	0.50	0.59	145.47	144.88
1984	46.65	5.49	71.59	5125.70	1.47	0.72	0.44	199.31	198.87
1985	39.31	12.20	58.28	3396.01	1.62	1.35	0.00	163.82	163.82
1986	46.03	30.14	50.97	2598.33	1.60	2.35	0.00	170.02	170.02
1987	35.04	28.54	33.47	1120.36	0.94	0.71	0.00	109.74	109.74
1988	52.29	14.10	72.52	5259.59	1.41	0.84	0.00	212.72	212.72
1989	27.77	14.08	38.22	1461.12	1.87	2.78	0.00	121.77	121.77
1990	39.27	12.97	53.69	2882.83	1.37	0.43	0.00	148.28	148.28
1991	18.05	13.17	20.25	410.02	1.82	4.05	0.00	71.60	71.60
1992	34.38	9.80	51.07	2608.61	1.69	1.73	0.00	153.66	153.66
1993	29.69	9.60	52.46	2751.66	2.67	7.68	0.00	183.38	183.38
1994	23.19	6.31	35.17	1236.61	1.86	3.12	0.00	113.04	113.04
1995	46.01	24.54	72.46	5250.42	2.40	6.16	0.00	250.28	250.28
1996	34.01	10.31	47.12	2220.66	1.70	2.75	0.00	152.46	152.46
1997	54.40	20.89	80.22	6435.14	1.99	3.03	2.40	251.40	249.00
1998	24.97	11.89	28.92	836.54	1.29	1.06	0.00	90.83	90.83
1999	18.59	9.35	22.06	486.51	0.88	-0.65	0.00	60.50	60.50
2000	19.46	4.75	37.55	1409.84	2.75	8.07	0.00	130.40	130.40
2001	23.26	15.96	24.54	602.29	1.17	1.26	0.00	80.68	80.68
2002	19.62	6.05	31.04	963.58	2.41	6.36	0.00	107.74	107.74
2003	19.49	13.64	20.42	417.05	1.59	2.80	1.05	70.96	69.91

2004	13.02	6.69	14.05	197.31	1.20	0.43	0.06	43.60	43.54
2005	34.33	22.77	36.37	1322.98	1.21	1.20	0.00	118.74	118.74
2006	23.90	13.14	27.38	749.61	1.11	0.15	0.00	82.02	82.02
2007	29.79	26.60	28.44	808.96	0.64	-1.06	1.54	79.21	77.68
2008	19.12	10.40	25.54	652.38	1.72	2.01	0.00	77.47	77.47
2009	21.55	8.73	28.74	826.23	1.78	2.79	1.53	93.42	91.88
2010	25.91	6.43	40.29	1623.30	1.86	2.60	0.20	124.39	124.19
Total	**31.35**	**14.67**	**41.93**	**2069.95**	**1.69**	**2.74**	**0.39**	**133.55**	**133.16**

Source: IMD, Pune and Directorate of Land Records, Jalandhar

From Table 1, in arid zone the year with highest mean annual rainfall was 1997, which recorded a highest mean value of 54.40 mm. The record indicated that the standard deviation correlating highest mean annual rainfall was 80.22 mm and the data was skewed right, meaning rainfall distribution was flat. Also, maximum annual rainfall standard deviation occurred in the same year 1997, meaning rainfall was highly dispersed with corresponding highest variance and high range value. In addition, maximum monthly rainfall also occurred in 1997 in August. The lowest mean annual rainfall occurred in 2004 with a value of 13.4 mm.

Table 2: Semi-Arid Zone: Descriptive statistics of annual rainfall (1981-2010)

Year	Mean (mm)	Median (mm)	S. D (mm)	Variance (mm)	Skewness	Kurtosis	Min (mm)	Max (mm)	Range (mm)
1981	39.92	24.93	49.94	2494.04	2.35	6.50	0.00	182.05	182.05
1982	48.25	27.11	52.36	2741.49	1.94	4.39	2.62	188.35	185.74
1983	65.92	49.00	63.96	4091.26	1.11	0.50	0.00	204.09	204.09
1984	72.77	14.10	103.01	10610.46	1.37	0.42	0.31	280.00	279.69
1985	62.70	28.73	94.28	8888.92	1.84	2.16	0.45	272.68	272.24
1986	49.03	24.43	52.32	2737.05	1.41	1.43	0.41	170.15	169.74
1987	33.26	25.10	31.13	969.13	1.41	1.20	1.15	97.26	96.11
1988	85.81	27.74	130.99	17158.48	1.81	2.53	0.47	409.15	408.68
1989	42.57	20.82	59.44	3533.14	1.75	1.91	0.62	174.03	173.41
1990	58.09	23.66	75.87	5756.14	1.20	-0.38	0.28	192.71	192.42
1991	35.08	23.62	35.69	1273.66	0.95	-0.16	0.00	105.54	105.54
1992	35.54	22.70	38.92	1515.00	1.45	1.10	1.08	116.20	115.12
1993	46.70	14.85	86.31	7449.35	2.93	9.08	0.54	307.04	306.50
1994	42.34	16.84	61.94	3836.71	1.70	2.04	0.00	191.80	191.80
1995	67.90	24.93	94.68	8964.10	1.67	2.27	1.24	300.29	299.05
1996	46.61	17.90	58.29	3397.31	1.61	2.35	0.35	190.61	190.26
1997	48.59	28.18	57.03	3252.16	2.11	4.10	5.48	197.88	192.41
1998	45.12	24.05	54.83	3005.94	1.60	1.85	0.33	173.40	173.08
1999	28.95	20.38	36.18	1308.75	1.64	2.72	0.00	119.27	119.27
2000	26.25	17.79	32.45	1052.86	1.94	3.83	0.15	110.87	110.72
2001	36.74	16.33	60.78	3694.10	2.74	8.08	0.38	216.31	215.93
2002	23.27	5.70	29.75	885.36	1.60	2.43	0.38	97.35	96.97
2003	36.41	17.32	42.44	1801.25	1.31	1.17	0.00	134.28	134.28
2004	27.03	19.39	27.81	773.28	1.36	1.80	0.00	93.75	93.75
2005	50.95	31.82	57.89	3350.82	1.38	1.26	0.00	184.12	184.12
2006	38.59	19.77	44.10	1944.86	1.22	-0.14	3.29	125.84	122.55
2007	33.27	23.45	32.36	1047.35	0.47	-1.51	1.54	85.57	84.03
2008	40.53	18.82	49.32	2431.99	1.27	-0.04	2.06	135.27	133.20
2009	31.76	15.13	39.21	1537.41	1.54	1.00	3.09	115.26	112.17
2010	40.35	20.48	43.50	1892.08	1.22	-0.01	2.17	126.16	123.99
Total	**44.68**	**22.17**	**56.56**	**3779.81**	**1.60**	**2.13**	**0.95**	**176.58**	**175.63**

Source: IMD, Pune and Directorate of Land Records, Jalandhar

From Table 2 it can be inferred that for semi-arid zone the maximum mean annual rainfall of 85.81 mm occurred in 1988 for the period under consideration. The maximum annual standard deviation of 130.99 mm and maximum rainfall range of 408.68 mm also happened in 1988. The high standard deviation value can be easily correlated with the highest rainfall range. The minimum mean annual rainfall occurred in 2002 (23.27 mm) and rainfall distribution for the period under study was flat.

Table 3: Dry Sub-Humid Zone: Descriptive statistics of annual rainfall (1981-2010)									
Year	**Mean (mm)**	**Median (mm)**	**S. D (mm)**	**Variance (mm)**	**Skewness**	**Kurtosis**	**Min (mm)**	**Max (mm)**	**Range (mm)**
1981	52.35	41.45	62.41	3894.62	2.19	5.89	0.00	226.95	226.95
1982	61.78	37.71	67.78	4593.70	1.69	2.71	2.31	231.64	229.33
1983	68.73	50.56	59.77	3572.85	0.98	0.33	0.00	193.09	193.09
1984	60.83	17.76	77.18	5956.95	1.15	0.14	0.40	221.72	221.32
1985	65.89	27.44	98.29	9661.81	1.79	1.94	1.17	275.45	274.28
1986	58.79	25.10	76.77	5892.92	1.81	2.37	0.00	243.74	243.74
1987	44.32	33.53	37.24	1386.74	1.11	0.49	0.00	119.78	119.78
1988	126.79	42.05	196.96	38792.66	1.64	1.34	0.00	557.21	557.21
1989	58.48	23.85	89.99	8098.78	1.88	2.20	0.20	251.48	251.28
1990	82.34	37.32	96.77	9363.76	0.89	-0.97	2.32	247.29	244.97
1991	66.41	37.30	82.39	6787.88	1.67	2.39	0.00	267.28	267.28
1992	60.82	42.15	75.51	5701.08	1.63	1.63	0.50	220.95	220.45
1993	74.18	16.13	158.37	25081.78	3.09	9.89	0.00	559.36	559.36
1994	70.99	26.47	108.60	11794.88	1.86	2.32	0.00	321.44	321.44
1995	95.25	37.52	144.63	20916.63	2.19	5.11	0.00	491.93	491.93
1996	76.68	25.29	104.32	10882.67	1.46	1.24	0.00	318.41	318.41
1997	74.06	43.37	91.06	8292.64	2.18	4.47	9.59	316.06	306.47
1998	83.42	57.76	90.45	8181.98	1.09	0.09	0.00	267.85	267.85
1999	55.63	35.68	74.27	5516.20	1.72	2.52	0.00	237.45	237.45
2000	48.69	25.14	59.06	3487.93	1.35	1.32	0.00	185.91	185.91
2001	60.68	21.83	87.18	7599.84	1.92	3.58	0.00	287.40	287.40
2002	32.20	8.61	42.20	1781.04	1.77	2.88	0.00	138.70	138.70
2003	59.25	25.95	72.26	5221.86	1.35	0.72	0.00	208.54	208.54
2004	52.91	31.16	62.57	3915.56	1.92	4.06	1.93	218.27	216.34
2005	61.16	44.79	71.54	5118.68	1.89	4.28	0.00	252.09	252.09
2006	49.06	21.79	57.81	3341.57	1.45	1.00	2.58	173.43	170.85
2007	48.47	27.86	47.81	2285.73	0.65	-1.12	1.70	129.45	127.75
2008	52.98	22.25	65.59	4302.12	1.21	-0.07	0.00	182.68	182.68
2009	55.29	21.36	72.45	5249.23	1.85	2.89	6.24	238.01	231.76
2010	46.17	14.33	65.98	4353.89	1.59	1.04	3.08	183.72	180.65
Total	**63.49**	**30.78**	**83.24**	**8034.26**	**1.63**	**2.22**	**1.07**	**258.91**	**257.84**

Source: IMD, Pune and Directorate of Land Records, Jalandhar

As can be observed from Table 3, the maximum mean annual rainfall for the period under study in dry sub-humid zone occurred in 1988 (126.79 mm) with corresponding maximum standard deviation of 196.96 mm and high annual range of 557.21 mm. The minimum mean annual rainfall occurred in 2002 with an amount of 32.20 mm for the years under consideration.

For all the three climatic zones, standard deviations were quite high in dry sub-humid and semi-arid zones suggesting high year-to-year fluctuations. Rainfall is more volatile in dry sub-humid and semi-arid zones in comparison to dry arid zone with low rainfall figure. Rainfall variability is also highest in dry sub-humid zone followed by semi-arid and lowest in arid zone.

Table 4: Arid Zone: Statistical Summary of monthly rainfall data (1981-2010)												
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Mean	13.2	19.6	19.6	13.6	14.9	37.9	107.1	89.6	44.9	7.4	3.4	5.1
Median	8.4	17.0	17.5	6.6	8.4	27.5	110.9	66.3	33.3	2.2	1.0	2.7
S. D	13.3	17.5	17.3	16.3	22.5	34.7	54.7	65.0	42.6	14.0	5.8	6.3
Variance	177.9	307.0	298.3	264.4	505.8	1203.9	2995.7	4229.3	1812.2	196.4	33.5	39.5
Skewness	1.4	1.0	1.2	1.5	3.2	2.0	0.4	1.1	2.3	3.0	2.5	1.8
Kurtosis	1.2	0.5	2.0	2.2	11.5	6.1	0.1	0.7	7.5	8.8	5.8	2.5
Min	0.0	0.0	0.0	0.0	0.0	0.4	14.8	4.8	0.8	0.0	0.0	0.0
Max	51.3	68.1	74.9	65.5	109.7	170.0	249.7	251.4	212.7	57.2	23.1	23.9
Range	51.3	68.1	74.9	65.5	109.7	169.6	234.9	246.6	211.9	57.2	23.1	23.9
Sum	395.3	588.8	587.6	408.1	447.4	1137.0	3212.5	2687.7	1346.5	221.9	100.8	152.6
C.V	1.0	0.9	0.9	1.2	1.5	0.9	0.5	0.7	0.9	1.9	1.7	1.2

Source: IMD, Pune and Directorate of Land Records, Jalandhar

Table 5: Semi-Arid Zone: Statistical Summary of monthly rainfall data (1981-2010)												
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Mean	20.2	29.4	21.7	16.9	19.0	44.0	146.4	130.4	79.3	11.0	6.3	11.7
Median	12.9	23.5	17.9	10.0	10.3	38.2	127.2	107.0	55.7	2.5	1.7	5.5
S. D	19.0	21.7	19.0	24.9	21.0	27.3	68.9	69.2	79.0	16.7	11.1	12.6
Variance	359.5	471.6	360.1	618.5	442.6	746.4	4746.3	4785.1	6245.6	280.1	124.0	159.4
Skewness	1.0	0.5	2.1	3.6	2.4	1.7	0.7	0.7	2.7	2.1	2.6	1.2
Kurtosis	0.0	-1.1	6.3	15.0	6.3	3.7	0.1	-0.3	10.0	4.2	6.6	0.3
Min	0.0	1.1	0.0	0.0	2.3	12.7	41.0	37.2	2.6	0.0	0.0	0.0
Max	64.7	69.7	93.8	129.2	97.3	135.3	307.0	300.3	409.2	68.8	45.8	40.9
Range	64.7	68.6	93.8	129.2	94.9	122.5	266.1	263.1	406.5	68.8	45.8	40.9
Sum	605.1	880.7	651.0	506.6	569.7	1318.9	4392.3	3912.4	2377.9	330.8	187.9	349.9
C.V	0.9	0.7	0.9	1.5	1.1	0.6	0.5	0.5	1.0	1.5	1.8	1.1

Source: IMD, Pune and Directorate of Land Records, Jalandhar

Table 6: Dry Sub-Humid Zone: Statistical Summary of monthly rainfall data (1981-2010)												
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Mean	28.7	42.7	32.9	19.0	21.2	64.0	219.5	198.8	99.5	14.3	6.8	14.4
Median	17.8	37.5	30.6	12.5	12.2	52.0	209.4	190.7	84.1	3.1	1.5	8.2
S. D	25.8	33.1	27.6	24.0	22.5	40.3	102.0	90.2	100.9	21.0	12.0	17.9
Variance	664.7	1092.3	763.8	577.5	506.9	1624.8	10394.7	8127.8	10190.0	440.6	144.2	319.9
Skewness	0.8	0.8	1.2	2.8	2.3	1.7	1.6	1.0	3.4	1.9	2.8	1.7
Kurtosis	-0.6	0.3	1.9	9.8	6.4	2.7	4.3	2.6	14.8	3.0	8.5	2.2
Min	0.0	1.5	0.0	0.0	0.4	15.0	58.8	26.1	2.3	0.0	0.0	0.0
Max	88.5	132.8	119.0	118.5	106.7	184.6	559.4	491.9	557.2	80.0	53.1	68.2
Range	88.5	131.3	119.0	118.5	106.3	169.5	500.6	465.8	554.9	80.0	53.1	68.2
Sum	861.5	1282.3	987.2	570.3	635.9	1920.6	6585.9	5963.7	2985.0	428.2	202.9	431.4
C.V	0.9	0.8	0.8	1.3	1.1	0.6	0.5	0.5	1.0	1.5	1.8	1.2

Source: IMD, Pune and Directorate of Land Records, Jalandhar

5.2 Monthly Rainfall Variability

Coefficient of variability is an indication of dependable rainfall while standard deviation indicates the spread of probability distribution and degree of uncertainty associated. It is evident from Table 4, that the coefficient of variation for the months of July through September (Southwest Monsoon season) is less than 1 which indicates lower variability from mean and similar observation is made for the months of February to March (Northwest monsoon season). The low coefficient of variability for the mentioned months is an indication of highly dependable rainfall. August in arid climate zone had the highest standard deviation indicating more uncertainty. The highest amount of mean monthly rainfall was recorded in July (107.1 mm) and contributed 28.5% of annual rainfall followed by August with 89.6 mm (23.8%) and lowest was in November with 0.89% of annual total followed by December with 1.35%. From the analysis, it was observed that rainfall is usually highest between July to September (major season) and February to March (minor season).

The month to month changes in rainfall are considerable over years. The standard deviation values of most months (April, May, September, October, November, and December) are greater or close to mean of these months (Table 5) which indicates high deviation from normal distribution, which is evident from coefficient of variation of these months which are close to one or more than one. In semi-arid zone precipitation values are much different from the mean value indicating high variability and less reliability. Lower coefficient of variation of precipitation amount in months indicate lower variability and greater dependability.

Table 6 indicates that in dry sub-humid zone from June to August, the rainfall variability is low and hence highly dependable. Considering the coefficient of variation, July and August shows the minimum variation from year to year in comparison to rest of the months. Since coefficient of variation of these months are close to 0.5, changes in precipitation from year to year in these months are low. July had the highest mean monthly rainfall of 219.5 mm followed by August (198.8 mm). The months with lowest rainfall is November (6.8 mm) followed by October (14.3 mm).

Table 7: Regression Statistic results for annual and monthly rainfall (1981-2010)						
	Arid Zone		**Semi-Arid Zone**		**Dry Sub-Humid Zone**	
Months	Regression Equation	P value	Regression Equation	P value	Regression Equation	P value
Jan	Y = -0.35X +718.14	0.215	Y = -0.52X + 1060.64	0.197	Y= -0.57X + 1170.38	0.301
Feb	Y = -0.10X +229.29	0.782	Y = -0.26X + 545.49	0.581	Y= -0.21X +455.88	0.772
Mar	Y = -0.67X + 1409.18	0.054	**Y = -1.03X + 2085.10**	**0.007**	**Y= -1.15X + 2335.79**	**0.046**

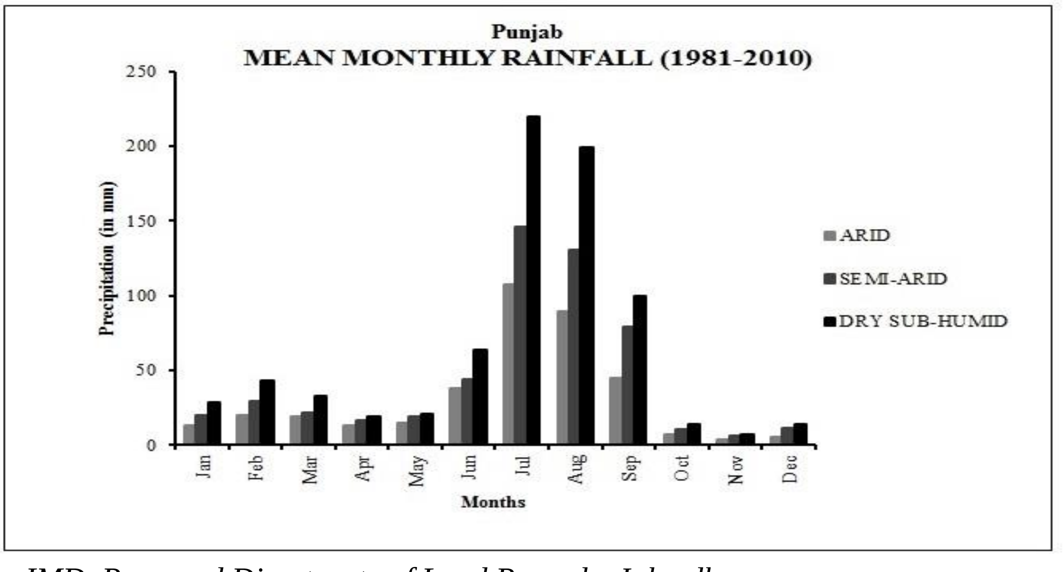
Apr	Y = -0.54X + 1093.08	0.116	**Y = -1.09X + 2201.43**	**0.034**	Y = -0.83X + 1676.17	0.102
May	Y= -0.80X + 1608.75	0.093	Y = -0.65X + 1322.01	0.144	Y = -0.31X + 638.26	0.524
Jun	Y= -0.32X + 669.70	0.673	Y = 0.57X -1084.13	0.335	Y = 0.88X -1687.64	0.310
Jul	**Y = -2.34X + 4782.35**	**0.040**	Y = -2.64X + 5410.95	0.068	Y = -2.02X + 4253.45	0.356
Aug	Y = -2.63X + 5343.12	0.053	**Y = -3.37X + 6857.55**	**0.018**	Y = -2.21X + 4600.18	0.253
Sep	Y = -0.98X + 1991.84	0.285	Y = -0.99X + 2048.80	0.563	Y = -0.067X + 1429.44	0.760
Oct	Y = -0.30X + 606.26	0.318	Y = -0.11X + 223.86	0.768	Y = -0.10X + 222.20	0.819
Nov	Y = -0.24X + 472.47	0.052	Y = -0.08X + 161.33	0.747	Y = -0.23X + 470.61	0.368
Dec	Y = -0.24X + 489.44	0.066	Y = -0.27X + 555.52	0.314	Y = -0.44X + 896.44	0.248
Annual	**Y= -0.80X + 1617.80**	**0.000**	**Y = -0.87X + 1782.38**	**0.003**	Y = -0.66X + 1371.76	0.080

Source: IMD, Pune and Directorate of Land Records, Jalandhar

5.3 Annual Trends

The results of linear regression trend analysis are presented in Table 7 covering arid, semi-arid and dry sub-humid climatic zones of Punjab respectively. In this trend analysis, trend of rainfall for 30 years from January to February has been computed independently. The linear trend lines of the monthly rainfall indicated a downward trend in all months and annual rainfall data for the arid zone. The probability value (P value) from the regression analysis for slopes of the monthly data represents no significant trend except for July (α =0.040), however which results in a significant trend in annual rainfall data (α = 0.0003). Additionally, the R-squared statistic also indicated weak relationship between variables rainfall and year. Table 8 revealed downward trend in rainfall for all months except June for semi-arid zone. However, significant decreasing trends are observed in months of March and April resulting in a significant overall decreasing trend in annual rainfall data (α = 0.003). Annual rainfall for dry sub-humid zone showed an overall decreasing trend for monthly (except June) and annual data. But these trends are statistically insignificant.

Figure 3



Source: IMD, Pune and Directorate of Land Records, Jalandhar

Figure 3 reveals that for arid, semi-arid and dry sub-humid zones the highest mean monthly rainfall was recorded in July for major season and February for minor season. The graph reveals that October, November and December are the driest months. Post-winter season (March and April) records higher rainfall than post-monsoon season (October and November).

6. Conclusions

- Rainfall characteristics especially variability and trends are necessary to optimally manage the scarce water resources and for proper management of hydro-related schemes in developed regions like Punjab. From the results of linear regression analysis, there is statistically significant (except dry sub-humid) decreasing trend in annual mean rainfall data among three zones under study.
- Mean monthly rainfall data from the linear regression analysis revealed decreasing trends in all of the months. However, some months in monsoon and post-winter season indicated statistically significant trends in monthly rainfall but a very weak correlation between rainfall and period. It is evident that there is significant detectable effect of climate change on both the annual and monthly trend in Punjab.
- Comparatively, arid zone recorded the lowest maximum and minimum annual rainfall of 652.8 mm and 156.2 mm, followed by semi-arid zone with 1029.7 mm and 279.3 mm. The dry sub-humid zone recorded the highest maximum annual rainfall of 1521.5 mm and minimum of 386.4 mm in the years 1988 and 2002 respectively. The arid zone demands special attention as an increasing aridity may result in acute water scarcity followed by prolonged droughts in the future.
- The overall situation reveals that rainfall regime has become variable and more volatile in dry sub-humid and semi-arid zones followed by dry arid zone, thus raising chances of extreme events.

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